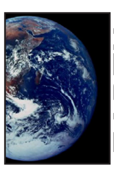
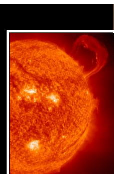
National Aeronautics and Space Administration


EARTH

Science Exploration and Research Office
2008 Capabilities Report


SPACE


OPTICS

Cover:
Photo of Hurricane Ike in the Gulf of Mexico taken in September 2008. Credit: National Oceanic and Atmospheric Administration (NOAA). For more on hurricane imaging, see page 12.

At right:
This composite of data from NASA's Chandra X-ray Observatory and Hubble Space Telescope is a new look for NGC 6543, better known as the Cat's Eye nebula. This famous object is a so-called planetary nebula that represents a phase of stellar evolution that the Sun should experience several billion years from now. Credit: X-ray: NASA/CXC/SAO; Optical: NASA/STScI. For more on X-ray astronomy, see page 24.

At right:
XRCF chamber's new configuration and the six hexagonal aluminum blanks used as Mirror Mass Simulators in the Ground Support Equipment Cryogenic Certification Tests. The Mass Simulators enabled the cryogenic structural verification test of the test stand. For more on our optical testing program, see page 38.

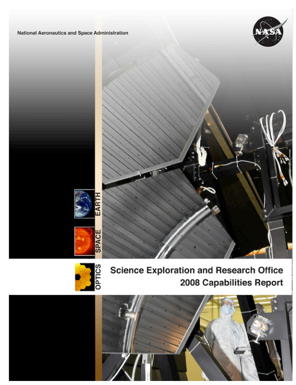


Table of Contents

Figure 1

This Chandra X-ray Observatory image shows Westerlund 2, a young star cluster with an estimated age of about one or two million years. Until recently little was known about this cluster because it is heavily obscured by dust and gas. However, using infrared and X-ray observations to overcome this obscuration, Westerlund 2 has become regarded as one of the most interesting star clusters in the Milky Way galaxy. It contains some of the hottest, brightest and most massive stars known. Credit: NASA/CXC/Univ. de Liège/Y. Naze et al.

Introduction

The year 2008 was incredibly successful for the Science and Exploration Research Office at the Marshall Space Flight Center. Highlights for the year include

- Successfully flying our soil moisture developmental instrument, named OMEGA, aboard the NASA P3 aircraft.
- Opening a second SERVIR office in West Africa.
- Discovering single sources of cosmic ray sources with our high energy balloon measurements.
- Observing first signatures of gamma-ray bursts with our Gamma-ray Burst Monitor aboard the Fermi mission.
- Playing a critical role in enabling the agency to move forward on the James Webb Space Telescope, its flagship science mission.

In addition, Chandra, the X-Ray Great Observatory, continues to yield unprecedented science results, unraveling fundamental physics riddles of the Universe, and Hinode results are yielding secrets about the sun's magnetic surface carpet.

And 2008 held even more accomplishments for the Science and Exploration Research Office:

- We produced invaluable applications of Earth Science data to help decision makers in developing countries solve societal, natural, and manmade problems.
- We established our lunar/planetary science team.

Strong, productive ties continue to evolve between our office and other agencies and institutions. Our employees have put forth tireless and creative efforts toward collaboration with other MSFC Science and Mission Systems offices and with our colleagues at the Bud Cramer National Space Science and Technology Center, the University of Alabama in Huntsville, the Universities Space Research Association, and the Von Braun Center for Scientific Innovation.

A clear vision propels and directs the Science and Exploration Research Office: we are an adaptive organization of diverse professionals who conduct scientific research and hardware development that enables MSFC to achieve Agency and National objectives with a focus on growth for the future.

Strong descriptive goals and norms define the manner in which we operate:

- Build and nurture existing excellence in Space and Earth science and optical capabilities that support and advance NASA objectives.
- Provide a consistent, coordinated, professional science interface for MSFC to NASA headquarters, the science community, and other agencies.
- Coordinate activities and strategies with partners in order to take advantage of and leverage opportunities we choose to pursue.
- Commit to develop a closer mutually beneficial working relationship with MSFC program and project to enhance opportunities.
- Develop a coherent long-term strategy and a confident attitude that results in competitive wins of investigations and missions.

The 2008 Science and Exploration Research Office Capability Report is not intended to document all of our research. Rather, it displays the extent and variety of our research and the results of our hard work and dedication.

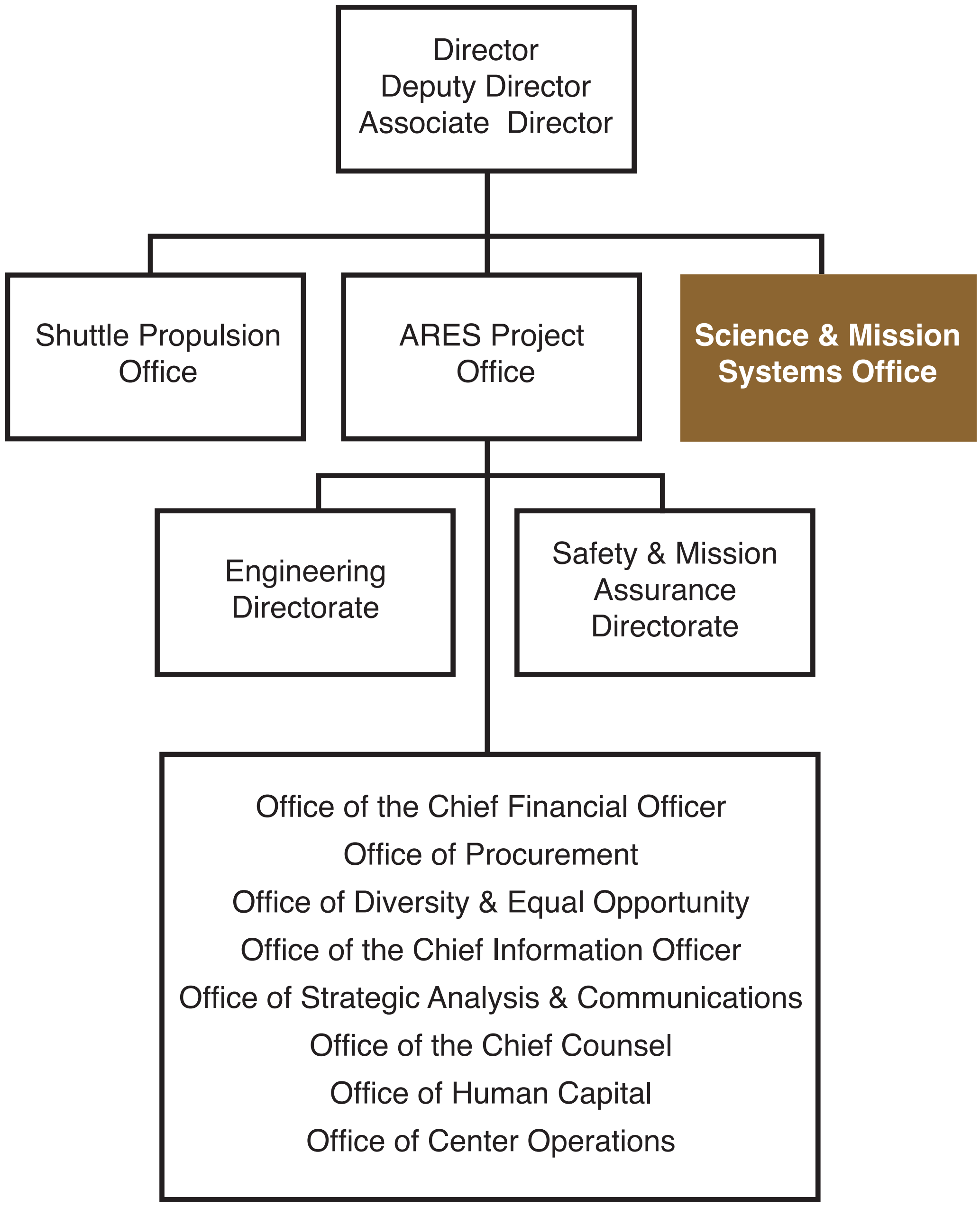
I strongly encourage you to read on. This report will show you who we are, describe the exciting things we do, and reveal to you the breadth of our capabilities.

Enjoy,

Jim Spann

James F. Spann, Ph.D., Manager
Science Exploration and Research Office

Marshall Space Flight Center Organization



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EARTH

Short-term Prediction Research and Transition (SPoRT) Program

Gary Jedlovec

The National Weather Service (NWS) delivers weather forecasts to American communities through its 122 Weather Forecast Offices (WFOs). The WFOs forecasting effectiveness depends on the ability to collect atmospheric observations, assimilate observations into numerical models, convert model analyses into national environmental information, and provide local warning and forecast services to affected communities. NASA's Short-term Prediction Research and Transition (SPoRT) Center accelerates the infusion of NASA Earth science observations, data assimilation, and modeling research into regional and local NWS forecasting and decision-making. Our experimental products focus on the regional scale and emphasize forecast improvements on a 0 to 24 hours time scale. This activity complements the National Aeronautics and Space Administration (NASA)/National Oceanic and Atmospheric Administration (NOAA)/Department of Defense Joint Center for Satellite Data Assimilation, which focuses on the larger, global scale and longer term forecasts (2 to 10 days).

SPoRT scientists work closely with the NWS Southern Region staff and forecasters at 12 local and regional WFOs to identify forecast problems and address them using timely, high resolution NASA observations and unique research capabilities. We develop techniques and integrate them into a test-bed (or rapid prototype) environment to demonstrate their operational feasibility. Promising data and forecast approaches are then integrated into current NWS decision support systems such as the Advanced Weather Interactive Processing system (AWIPs) and follow-on advanced systems. Forecasters access and display the supplemental information integrated with their standard product suite to generate weather guidance and advanced forecasts. They then provide feedback about the usefulness of the new tools to generating more accurate weather forecasts. SPoRT staff members also train forecasters on new data, products, or capabilities in the form of science sharing sessions, informative presentations, and special training modules.

Figure 2

MODIS imagery delineates snow on the ground (red and orange) from clouds (white).

Some of the key forecast problems the SPoRT team focuses on in the Southern Region include:

- Correct diagnosis of cloud cover, fog and visibility (particularly at night)
- Night-time minimum temperature forecasts
- Precipitation - areal coverage, amount, and timing of precipitation
- Severe weather (hail, high winds, lightning, and tornados) - improved accuracy and advanced warning / lead time
- Identifying the location of convective activity
- Diagnosis of atmospheric moisture variability as it relates to minimum temperatures, clouds, and precipitation
- Diagnosis and prediction of atmospheric stability and winds at the regional and local scales
- Data voids (Gulf of Mexico, Mexico, ocean regions) which contribute to forecast errors in cloud cover, precipitation, and basic state parameters
- Land breeze / sea breeze weather
- Accurate marine weather forecasts (offshore to 60 nm temperature, winds, seas state, etc.)

SPoRT also works collaboratively the other federal agencies, universities, and private sector partners. The program will vigorously continue its efforts to provide both a means and a process for effectively transitioning Earth science observations and research capabilities into NWS and private sector operations and to decision makers at the regional and local levels. Transitioning emerging experimental data and products into operations through the SPoRT infrastructure will help NASA foster and accelerate this Earth science strategy over the coming years and move future operational sensors into mainstream operations.

Earth Science Applications

Doug Rickman

With work ranging from developing new technologies to applying datasets and observations to societal problems, applied science activities form a significant focus for the Earth Science Office. The Earth Science Office Applications Team has studied the impact of land cover and land use patterns on the support tools used to make decisions about air quality. Land surface characteristics (e.g., albedo, surface roughness, fractional vegetative cover) exert a significant influence on the surface energy budget. Such parameters can be extracted from remote sensing data. An additional component of the work has been the incorporation of growth modeling for urban areas into air quality models. Figure 3 shows the effects a mitigation process might have on urban ozone levels at 2:00 pm and 7:00 pm and represents the kind of analysis used to help urban planners meet environmental air quality goals.

Our Earth Science Office has an international standing in public health applications. In 2007 and 2008 ESO led sessions on the use of remote sensing for tropic medicine. ESO is an element in the HELIX-Israel effort, linking air quality from remote sensing with health outcome data. The Office organized an invited session for the annual meeting of the American Thoracic Society in Toronto, May 2008. Working with the School of Public Health at the University of Alabama at Birmingham (UAB) led by Drs. Leslie McClure and George Howard, the team is exploring potential relationships between air quality and stroke. This research uses NASA satellite assets and the REasons for Geographic And Racial Differences in Stroke (REGARDS) program funded by the National Institute of Health.

ESO members are also involved in the new technology development project, the Observing Microwave Emissions for Geophysical Applications (OMEGA) study, which will create a soil moisture measurement system that uses microwave radiation from airborne and satellite platforms. Soil moisture is a key parameter for understanding Earth's climatology and global water cycle. A growing body of scientific literature shows that observations of soil moisture would lead to significant improvements in weather and flood forecasting. Other applications of remote soil moisture observations include irrigation, pesticide, and herbicide scheduling, early detection and monitoring of crop disease and drought, fire monitoring and forecasting, soil trafficability, and prediction of aerosol dust production. The OMEGA story will lead to improvements in all of these areas. One of their instruments saw first light in October 2008 test flights.

Our ESO team members continue to develop critical relationships beyond the existing norms for a science organization. For example, the team has successfully built cooperative partnerships with NASA's Academic Affairs Office and with UAB's School of Public Health. Additional partnerships were built with several institutions not normally associated with NASA-related work, for example the Centers for Disease Control and Prevention, the United States Geological Survey, the University of Mississippi Medical Center, and Schools of Public Health at UAB and Pennsylvania, tribal colleges, Israel Center for Disease Control, and various universities within the United States and in Puerto Rico.

In all cases, these relationships are intended to bring NASA assets and information to bear on significant problems that must be solved by decision-makers at all levels of government. Expanding beyond this, the team is planning to work with non-governmental organizations dedicated to making substantial improvements to the infrastructure of cities in developing countries. A case in point is the relationship with World Resource Institute and mass transit in Istanbul.

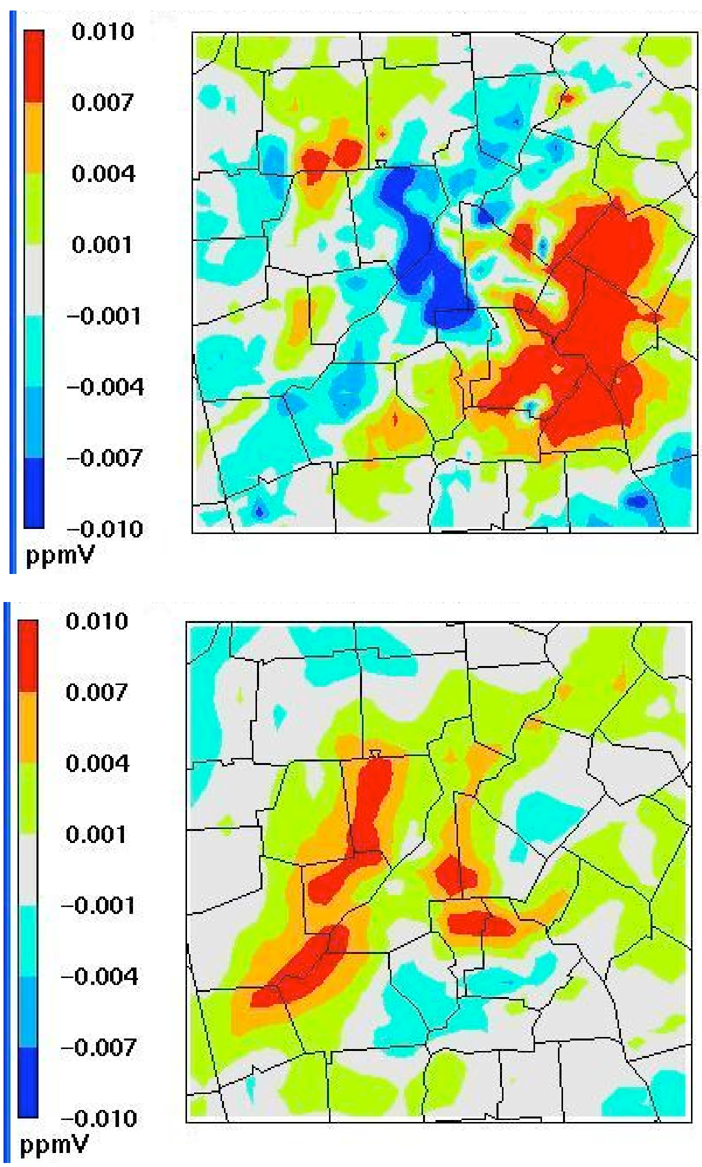


Figure 3

Surface ozone concentration differences (parts per million by volume, ppmV) predicted by the Community Multiscale Air Quality (CMAQ) model, averaged over a nine-day episode in August 2000, at 7:00 PM LDT (top) and 11:00 PM LDT (bottom) for the Atlanta, GA metropolitan area. Differences are between model predictions from model simulations using the USGS land use data set minus predictions using the National Land Cover Data (NLCD) merged with the LandPro99 data set. The differences show the important role of the land surface in modeling ozone and other air quality components.

Soil Moisture Remote Sensing

Charles Laymon

The global soil moisture mission addresses two questions: (1) How will water cycle dynamics change in the future? and (2) How are the variations in local water resources related to global climate variation? Soil moisture estimates over the Earth's land surface help determine the amount of water stored in and moved through the top layers of soil. This information is critical to a host of scientific processes and can lead to improvements in weather prediction. The study of soil moisture also has practical applications for agriculture, water resource planning, disaster management, and military trafficability determination.

The NSSTC soil moisture team of scientists has developed or has experience in the use of a suite of models and analytical tools pertinent to soil moisture remote sensing.

We have used radiobrightness models ranging from simple (single-layer) Fresnel reflectance models to the coherent wave radiative transfer model for a layered soil medium. Our team has long used the standard single-frequency and polarization retrieval schemes and have gained experience with multi-polarization, multi-angle optimization/polarization ratio-based retrieval schemes. We recently developed a combined passive and active retrieval scheme that solves for multiple parameters using optimization. Our team has 20 years experience with the Simulator for Hydrology and Energy Exchange at the Land Surface (SHEELS) land surface hydrology model, which is coupled with a forward radiobrightness model and a Kalman filter for soil moisture modeling and remote sensing data assimilation. We have recently implemented SHEELS within the Land Information System modeling framework.

Our team has developed an optimal deconvolution model to more accurately assign observations made by microwave instruments to an earth grid based on sensor response functions. This algorithm uses over-sampling of remote observations to enhance the resolution of brightness temperature or soil moisture products. We have coupled a Kalman filter with SHEELS for remote sensing applications. With SHEELS now operating in LIS, we can use the

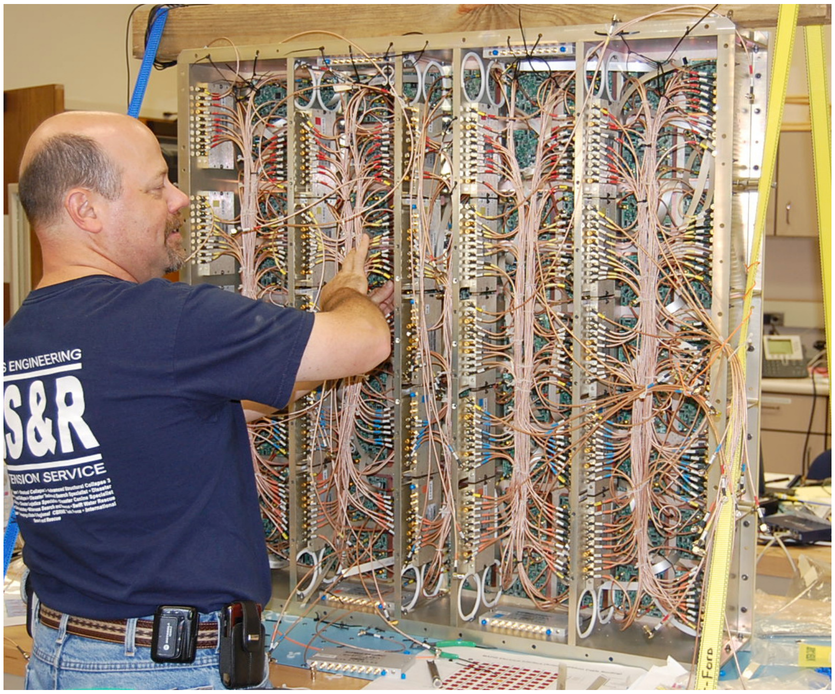


Figure 4 **MAPIR antenna assembly in the OMEGA Sensor Engineering Laboratory**

Figure 5 **P-3B Orion aircraft in which MAPIR was integrated for a recent experiment**

Figure 6 **MAPIR Command and Control System in the P-3 aircraft**

ensemble Kalman filter tools to extend our data assimilation abilities to regional, continental and global scales.

In addition to the science modeling tools, the OMEGA (Observing Microwave Emissions for Geophysical Applications) team has recently started developing instruments to assist in soil moisture research and validation of space borne sensors. We are in the process of developing a truck-mounted active and passive system comprised of an L-band fully polarimetric radar (1.26 GHz) and radiometer (1.413 GHz).

Our team completed an engineering model of the Marshall Airborne Polarimetric Imaging Radiometer (MAPIR), a fully polarimetric airborne phased array radiometer. The digital back end to the MAPIR radiometers was developed by the University of Michigan and has implemented the Agile Digital Detector for detection and mitigation of radiofrequency interference.

A spectrum analyzer also allows us to record and characterize the spectral characteristics of radiofrequency interference. MAPIR was recently integrated into NASA's P-3B Orion aircraft and flew 8 missions in October 2008 as part of the Soil Moisture Active Passive Verification Experiment 2008 (SMAP-VEX '08).

Hurricane Imaging Radiometer

Tim Miller

The Hurricane Imaging Radiometer (HIRAD) is an innovative technology development offering the potential of new and unique remotely sensed observations of both extreme oceanic wind events and strong precipitation from either an aircraft (including possibly an uninhabited aerial system) or satellite platforms.

The instrument is based on the airborne Stepped Frequency Microwave Radiometer (SFMR), which is a proven aircraft remote sensing technique for observing tropical cyclone ocean surface wind speeds and rain rates, including those of major hurricane intensity. The proposed HIRAD instrument advances beyond the current nadir viewing SFMR to an equivalent wide-swath SFMR imager using passive microwave synthetic thinned aperture radiometer technology. This sensor will operate over 4-7 GHz (C-band frequencies) where the required tropical cyclone remote sensing physics has been validated by both SFMR and WindSat radiometers.

HIRAD incorporates a unique, technologically advanced array antenna and several other technologies successfully demonstrated by the NASA's Instrument Incubator Program. A brassboard version of the instrument is complete and has been successfully tested in an anechoic chamber, and development of the aircraft instrument is underway.

HIRAD will be a compact, lightweight, low-power instrument with no moving parts that will produce wide-swath imagery of ocean vector winds and rain during hurricane conditions when existing microwave sensors (radiometers or scatterometers) are hindered. Preliminary studies show that HIRAD will have a significant positive impact on analyses as either a new aircraft or satellite sensor. MSFC and partner investigators hope to deploy HIRAD in a 2010 NASA hurricane research mission on an aircraft or uninhabited aerial system.

MSFC is partnering with NOAA's Hurricane Research Division, University of Michigan, and University of Central Florida for both science and engineering efforts, with the major construction implemented in-house.

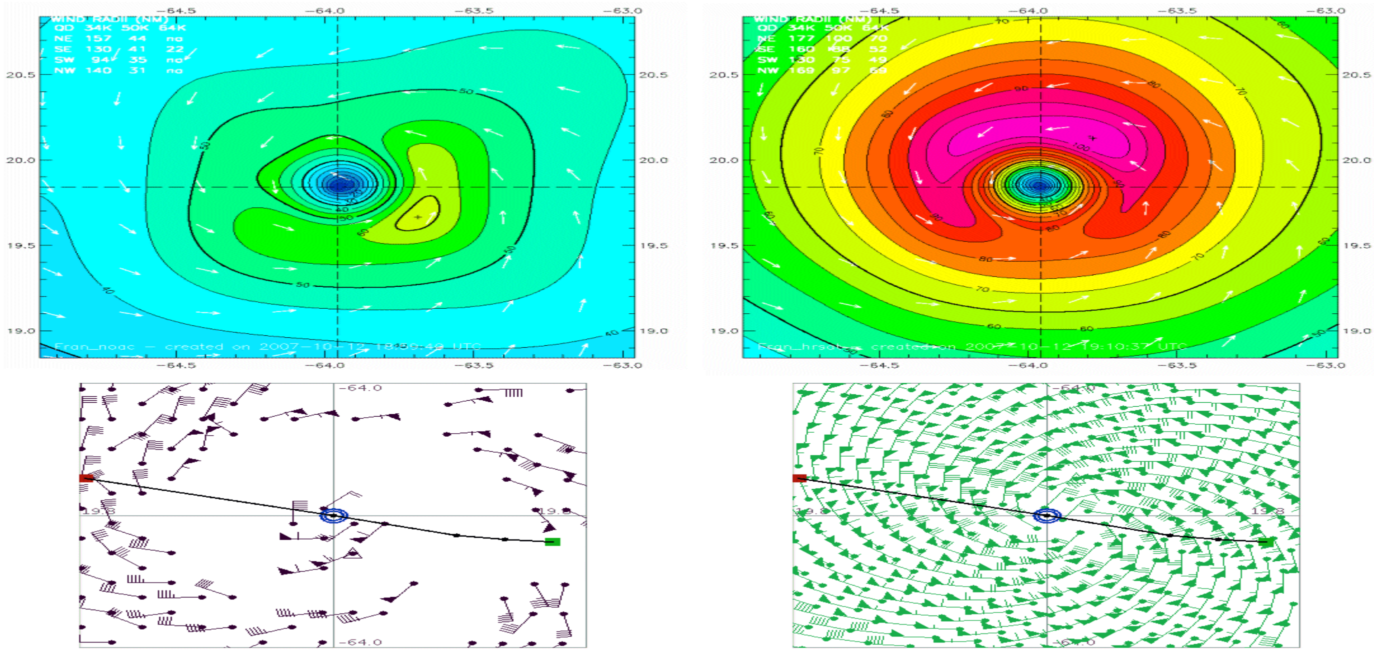


Figure 7 (above) **The figure on the left shows a depiction of the hurricane vortex as analyzed using data only from current satellites, and the one on the right shows the same analysis when a simulated HIRAD satellite is used to gather data.**

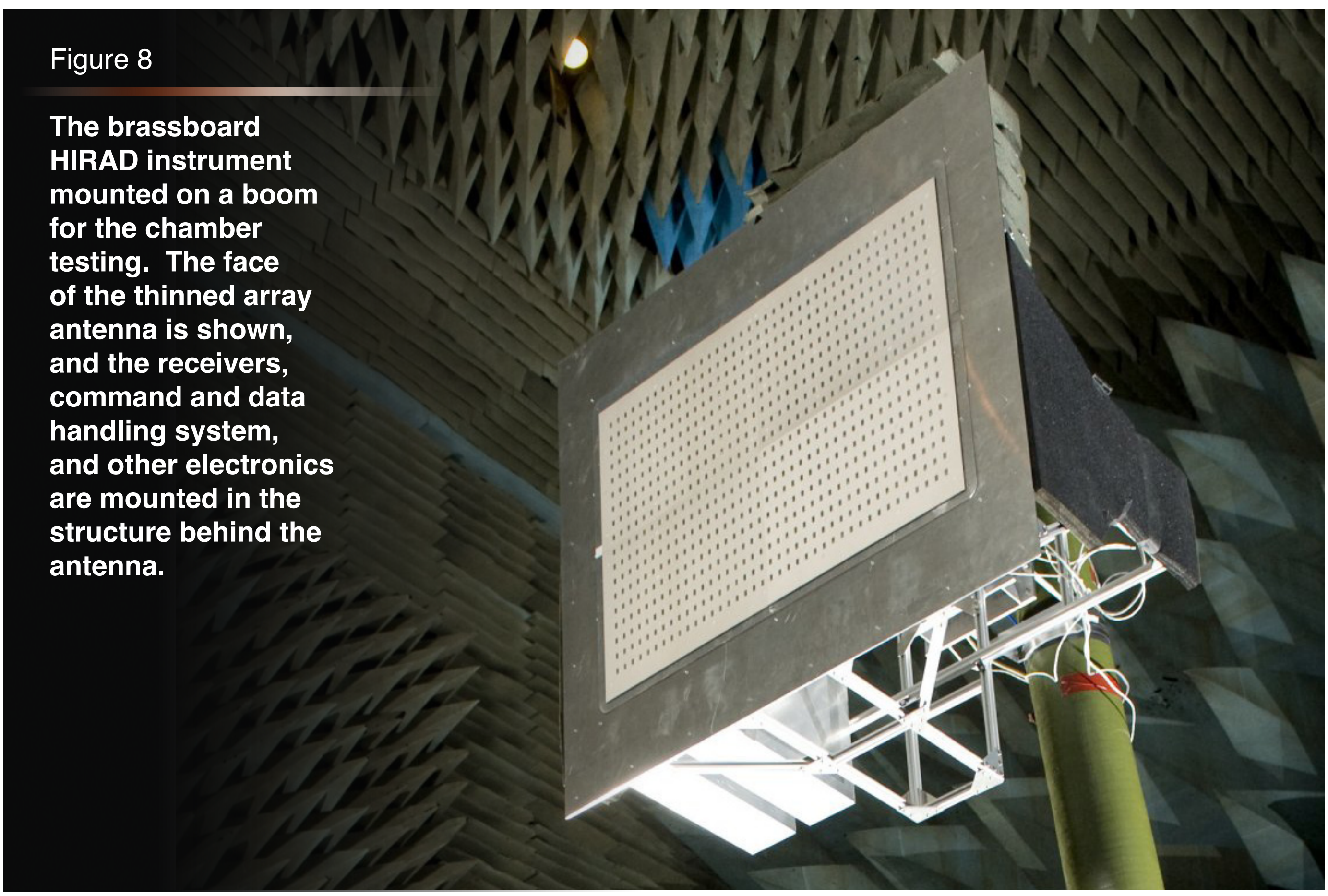


Figure 8

The brassboard HIRAD instrument mounted on a boom for the chamber testing. The face of the thinned array antenna is shown, and the receivers, command and data handling system, and other electronics are mounted in the structure behind the antenna.

Water and Energy Cycle

Pete Robertson

The exchange of water and energy among components of Earth's climate system strongly shapes the habitability of our home planet. Over the past 20 years, NASA observations and analysis have enabled the synthesis of data sets documenting various component fluxes and variables of the water and energy cycles. Beginning with rainfall from the Global Precipitation Chemistry Project, cloud attributes from the International Satellite Cloud Climatology Program, and Top of the Atmosphere broadband radiative fluxes from the Earth Radiation Budget Experiment, we now have a new generation of spacecraft and sensors augmenting the climate record.

These latest spacecraft include the Tropical Rainfall Measuring Mission (TRMM), Terra, Aqua, Aura and CloudSat; new sensors such as the CloudSat 94 GHz radar and Microwave Limb Sounder on Aura allow retrieval of vertical cloud and moisture structure on a global basis with unprecedented detail.

These new measurements will help answer important NASA ESD strategic science questions that form a major focus of our work at MSFC: (1) How are global precipitation, evaporation and the cycling of water changing? (2) What are the effects of clouds and surface hydrologic processes on Earth's climate? (3) How are variations and extremes in local weather, precipitation, and water resources related to global climate variation? Our Earth Science Office scientists work in collaboration with colleagues at Goddard Space Flight Center and other institutions to advance scientific understanding in these areas.

A major theme of our work this past year has been evaluating data sets to understand the extent of ice clouds produced by thunderstorms penetrating high above the freezing level in the tropical atmosphere. The production of condensate and associated detrainment of water vapor is key to understanding the stability of climate and what role we might expect tropical convection to play in future climate change, whether due to natural variability or anthropogenic forcing. Ice crystals, snow, and graupel have particle size distributions, shapes and densities that vary dramatically—not just over geographic regions but within individual clouds. Multiple measurements of a given cloud system by different sensors are needed to sort out and quantify the mass of ice present and its radiative properties.

Figure 9 shows the strategy we have adopted to address some of these uncertainties. Near-simultaneous retrievals of ice water path (IWP), or the column-integrated mass of ice, have been assembled from three instruments: the Microwave Humidity Sounder (MHS); Moderate Resolution Spectroradiometer (MODIS); and CloudSat millimeter cloud radar. While MHS and MODIS provide mapping of IWP estimates at approximately 15 and 5 km resolution, respectively, CloudSat yields vertical profiles of ice water content, but along a "curtain" about 1.2 km wide. Each of these instruments "sees" a portion of the IWP — the Advanced Microwave Sounding Unit – B resolves large ice present in thunderstorms, MODIS focuses on the thinner clouds that trap heat in the climate system, and CloudSat provides vertical structure of each.

We expect analyses of these retrievals will help refine algorithms for cloud and precipitation ice and serve as a benchmark for validating climate model simulations of cloudiness, water vapor and the effect that moisture has on regulating the temperature of our planet.

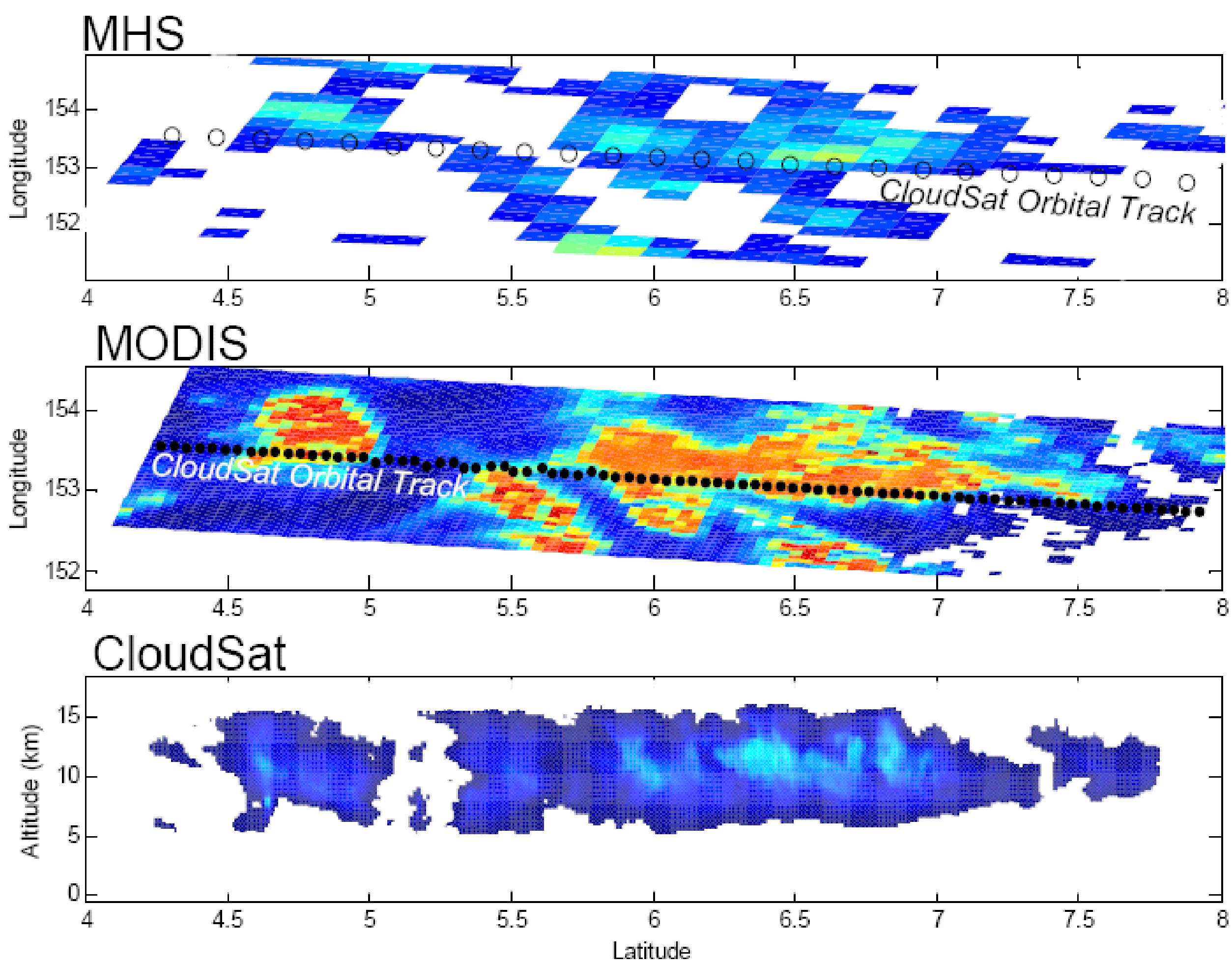


Figure 9 **Orbital swath data showing ice water path retrievals from MHS (top), MODIS (middle) and ice water content from CloudSat (bottom). Reddish colors indicate more ice water amounts and bluish colors less.**

Climate Dynamics

Pete Robertson

Earth's physical climate system consists of interacting atmosphere, ocean, cryosphere and land / biosphere components. It is a formidable task to model the physical processes in these subsystems and the fluxes of water, chemical constituents, heat, and momentum among them. Marshall scientists are working collaboratively with the Global Modeling and Assimilation Office at Goddard Space Flight Center to improve the representation of clouds and precipitation processes in the Global Modeling and Assimilation Office atmospheric modeling system, called the Global Earth Observation System of Systems, or GEOSS. This atmospheric model allows earth scientists to integrate the diverse space-based measurements of atmospheric state variables (e.g., temperature, wind velocity, moisture) and derive associated fluxes of radiation, water, and heat. Linking our space-based observations with physically detailed numerical models is a crucial step to improving our understanding of climate dynamics and the predictability of future climate states.

We have recently implemented an alternative subsystem in GEOS-5 for representing the aggregate effects of precipitating convective clouds on atmospheric circulation. Since global models can't be used to represent individual clouds in these computations, we instead statistically model bulk cloud condensation, evaporation, and vertical transport.

The physical processes by which clouds and atmospheric water vapor modulate the earth's global heat budget are still not well treated in climate models. These shortcomings limit our ability to anticipate future climate states -- for example, how much warmth will occur and where significant changes in rainfall might exist. Water vapor and cloud cloudiness variations on "weather" time scales produce radiative and turbulent energy fluxes across the ocean surface that get integrated in time. Much of the interannual to decadal variability in climate that we experience results from the huge thermal inertia of the oceans that in effect acts as a "flywheel" in the climate system. The resulting slow surface temperature variations of the upper ocean provide the low frequency forc-

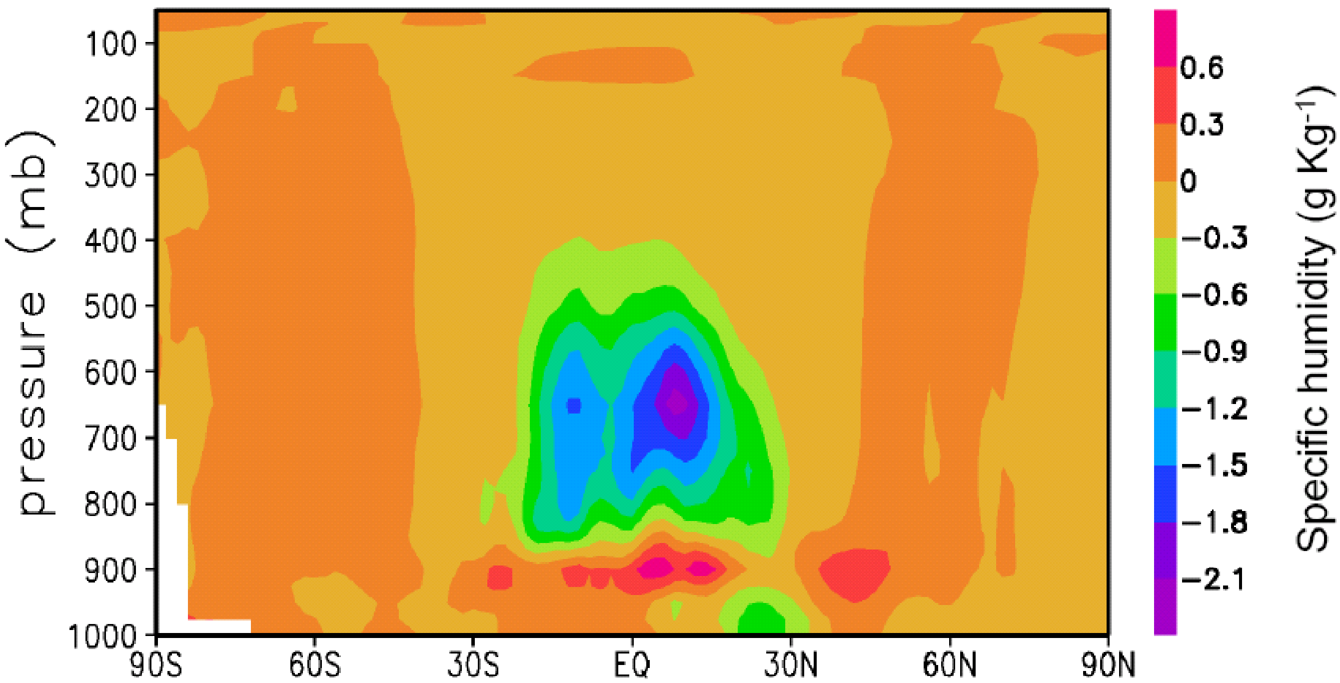


Figure 10 **Vertical cross section (pole-to-pole) showing the difference in water vapor that results from using the KF alternative convective parameterization**

ing back to the atmosphere. Our research here at Marshall involves developing better physical representations of how convective clouds pump moisture out of the planetary boundary layer to produce the right amount of moistening in the troposphere, yet also making our representations reflect the correct amount of solar radiation to keep the planetary energy balance nearly invariant.

Figure 10 shows changes in water vapor distribution in the model atmosphere using this alternative parameterization (termed Kain-Fritsch, or KF, after its developers). The zonally-averaged vertical slice through the atmosphere indicates that within the tropical portions of the Earth's atmosphere (30° N/S), the KF parameterization results in a somewhat drier state between 850 and 400 mb (approximately 1.5 to 6 km in altitude). Below this the atmosphere is more moist. This change is in the direction of better agreement with observations. Interestingly, we have found that this alternative way of treating precipitating clouds allows a somewhat improved simulation of the intensification of tropical storm systems. We are conducting experiments to determine the generality of this result.

Even with increased computational capacity, global model simulations used in seasonal to interannual prediction of weather extremes will likely need improved statistical representations of cloud physics. The work here at MSFC will focus on refining these methodologies and testing them using observations from a variety of space-based measurements. Among these will be precipitation and cloud measurements from the Tropical Rainfall Measuring Mission and the CloudSat radar.

SERVIR

Dan Irwin

SERVIR is the Regional Visualization and Monitoring System for environmental management and disaster support for Mesoamerica, the Caribbean, and now, East Africa. Inaugurated in February 2005, SERVIR provides the region with a public access environmental information system that integrates NASA satellite observations and predictive models with other geographic information (sensor and field-based) to monitor and forecast ecological changes and respond to natural disasters. A second SERVIR facility opened in Nairobi, Kenya, in November 2008 to improve scientific knowledge and decision-making in a range of application areas such as biodiversity conservation, disaster management, agricultural development, and climate change adaptation. Initial work covers flood potential modeling, flood forecasting, and Rift Valley Fever risk mapping.

The driving question behind SERVIR's development has been: How can we best leverage NASA Earth Systems Science to both develop and disseminate ecological monitoring solutions to countries in Mesoamerica and now East Africa?

Over the past few years, the SERVIR team, which is coordinated from MSFC, has joined forces with scientists and program developers from NASA and various other institutions to create tools and products to assist decision-makers in Mesoamerica and the Caribbean. This collaboration has resulted in a suite of web-accessible tools, such as an air quality assessment utilizing the Moderate Resolution Imaging Spectroradiometer (MODIS), near real-time weather forecasting from Geostationary Operational Environmental Satellites, daily wildfire monitoring using MODIS imagery, and weather model forecasts such as MM5 and Weather Research and Forecasting Model, to name just a few examples. Through these collaborations and pioneering efforts, SERVIR has established itself as the preeminent environmental data management and decision-support resource in the region.

SERVIR makes extensive use of and integrates NASA satellite observations and predictive models along with other geographic information to monitor and forecast ecological changes and respond to natural disasters in Mesoamerica such as extreme weather events, forest fires, floods, and volcanic eruptions. Initially addressing only ecological conservation, the project has since expanded to address a wide range of societal issues. In fact, SERVIR was presented to the heads of state from Mesoamerica and the Caribbean at the May 2008 Presidential Summit on Climate Change in San Pedro Sula, Honduras.

SERVIR also takes a leadership role in the development of disaster products during natural disasters in Mesoamerica and the Caribbean and has been designated as a project manager to develop satellite-based disaster products under the International Charter on Space and Major Disasters. To date, the SERVIR team has addressed 16 disasters in Mesoamerica and the Caribbean including hurricanes, flooding, landslides, and volcanic eruptions.

SERVIR products are freely and publicly available via the SERVIR website (www.servir.net), which is oriented towards a variety of user groups including scientists, educators, policymakers, and the general public. The SERVIR website provides (1) raw satellite data, (2) online maps, (3) decision support products, and (4) interactive 3D visualizations.

The SERVIR Mesoamerica and Caribbean facility is located at the Water Center for the Humid Tropics of Latin America and the Caribbean (CATHALAC) in the City of Knowledge, Panama. The newly dedicated SERVIR-East Africa facility is located at the Regional Center for Mapping of Resources for Development (RCMRD) based in Nairobi, Kenya.

Ongoing research and collaborative efforts have demonstrated the value of a system that leverages NASA Earth Systems Science to support environmental monitoring and effective sustainable development. The visibility and success of SERVIR over the past several years have garnered interest in migrating the SERVIR model to many other geographic regions.

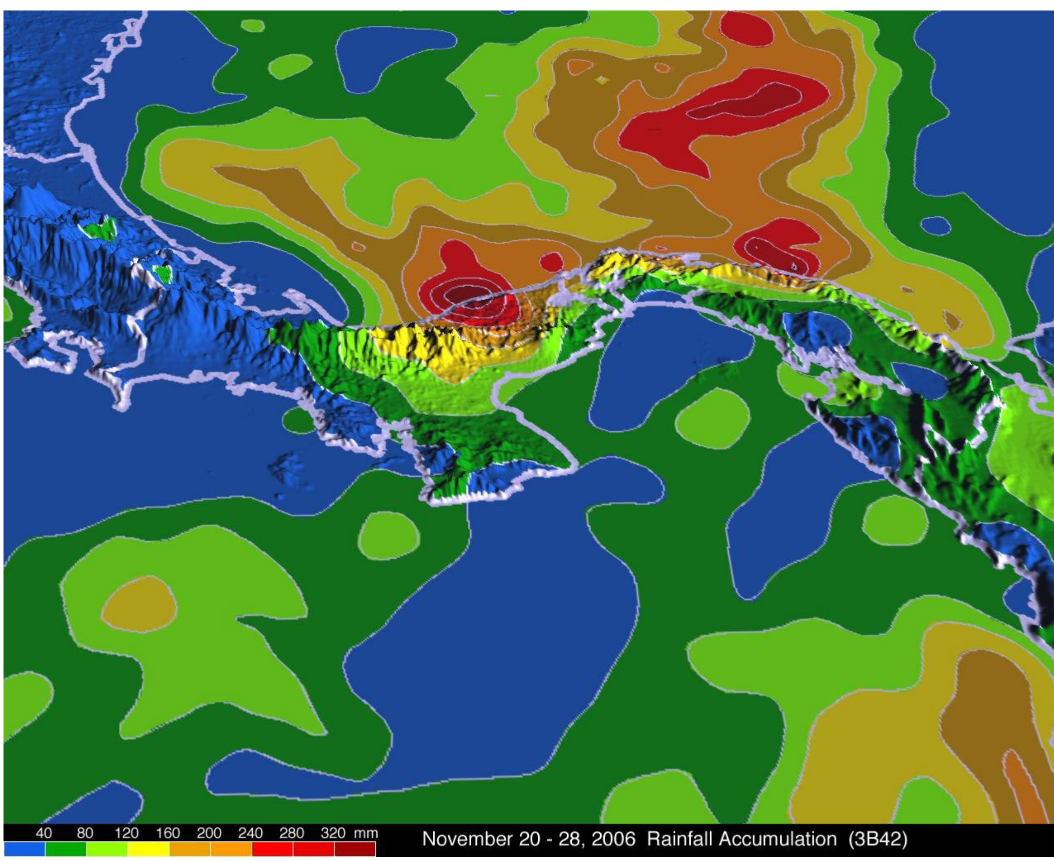
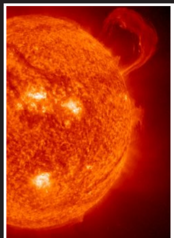


Figure 11

Accumulated rainfall during Panama floods as detected by the Tropical Rainfall Measuring Mission (TRMM)

TRMM image courtesy Hal Pierce, Dr. Robert Adler/ TRMM Project.



SPACE

Solar Activity Predictions

David Hathaway

Solar activity impacts us in many ways and on many time-scales, from minutes to millennia. The Heliophysics Team plays critical roles in predicting solar activity on two time-scales: (1) hours-to-days in predicting solar flares and coronal mass ejections (CMEs) that can impact satellite operations and astronaut activities; and (2) months-to-years in predicting the solar activity cycle that can impact mission planning.

The short-term predictions of flares and CMEs involve techniques that are under development but nearly operational. The long-term predictions involve techniques that are fully operational but known to be less reliable for the rising phase of the 11-year activity cycle. The Sun has just passed through the minimum between activity cycles, and the rise of the next cycle has begun. However, the level of activity for the next few years remains uncertain at this critical time.

Two years ago, NASA convened a panel of 12 experts from around the world to address this prediction problem. Our personnel made several significant contributions to the panel and its predictions. NASA convened similar panels prior to the previous two cycles, and those panels reached consensus on their predictions. This time, however, the panel is evenly split. Prediction techniques that were found to be reliable roughly agreed with each other for the last two cycles but wildly disagree for the next cycle. One set of techniques indicates a small amplitude cycle, while another set indicates a large amplitude cycle. The panel released its preliminary predictions in April of 2007 and will continue to monitor activity and revise the predictions accordingly as the next cycle continues to rise. Meanwhile, research efforts are underway to reconcile the different predictions.

[Note: get our current prediction plot from: http://solarscience.msfc.nasa.gov/predict.shtml]s.

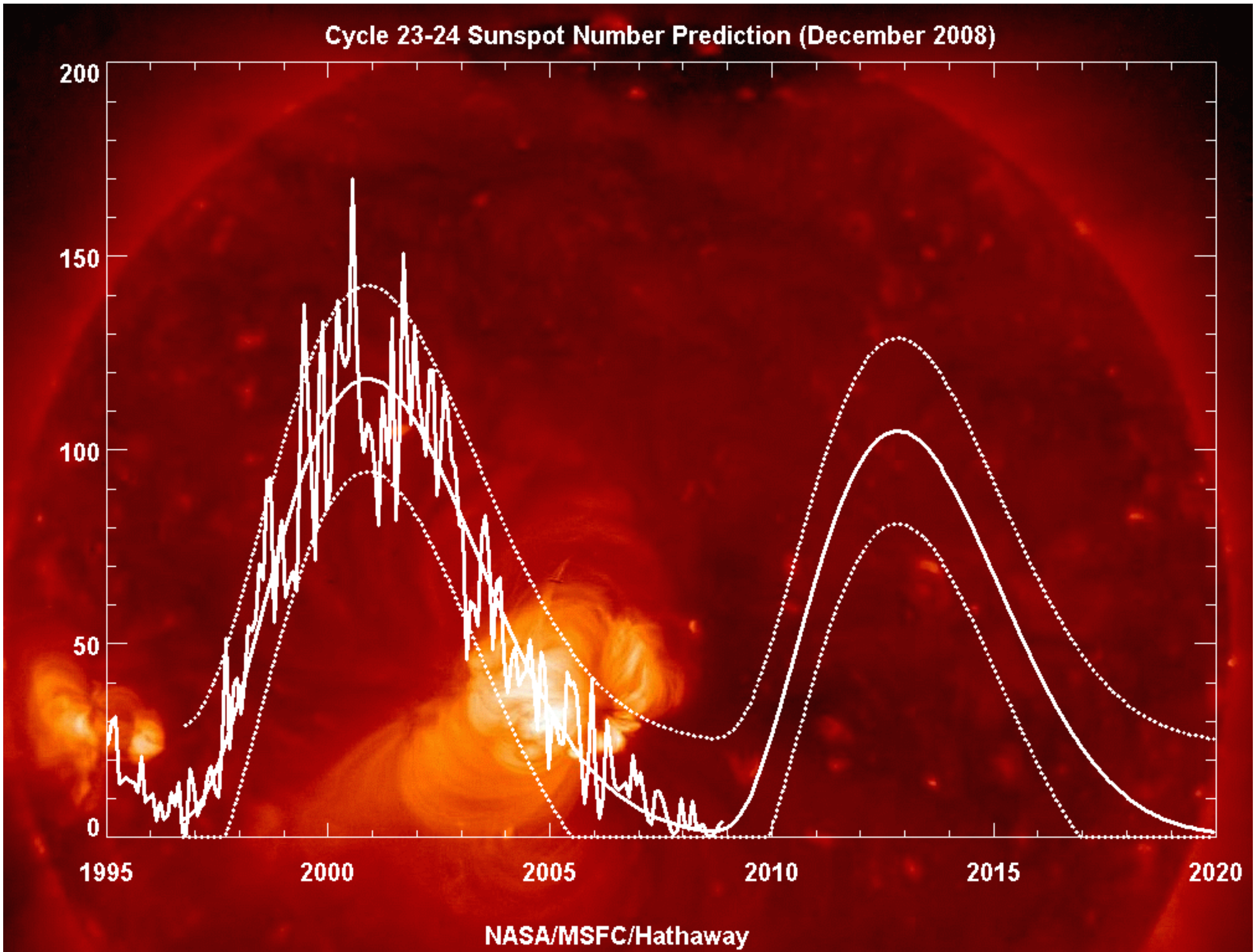
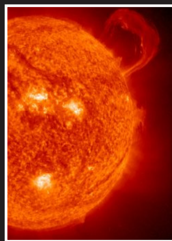


Figure 12

Sunspot cycle predictions. The jagged line in this figure represents the monthly averages of the daily sunspot number counts from Jan. 1995 to Nov. 2008. The smooth line passing through it and on to Dec. 2019 is our prediction of the smoothed behavior of the sunspot number counts. The segment of the line through the observed sunspot number values is from a prediction made in late 1998 based on the sunspot numbers up to that time - it predicted the actual sunspot numbers exceedingly well.

The extension of the prediction through the next sunspot cycle (Cycle 24) is based on recent geomagnetic activity - this prediction is subject to change as the new cycle starts. The dotted lines above and below the prediction line represent the expected range of activity above and below that predicted. The background image is from the Hinode spacecraft instrument XRT. The NASA science instruments on Hinode were managed by MSFC.



FERMI Gamma-Ray Burst Monitor

Charles Meegan

The gamma-ray astronomy team at MSFC has long contributed to studies of gamma-ray bursts, now known to be the most powerful explosions in the universe. The Burst and Transient Source Experiment, also referred to as BATSE, on the Compton Gamma-Ray Observatory made pioneering observations from 1991 until 2000, obtaining compelling evidence that the sources of gamma-ray bursts were located in distant galaxies. Current theories postulate that the sources are a rare type of core-collapse supernova of a massive, rapidly rotating star, or the merger of two neutron stars or of a black hole and a neutron star.

Our team's current focus is the Gamma-Ray Burst Monitor (GBM) on the Fermi Gamma-Ray Space Telescope. Fermi (Figure 13) is a high-energy gamma-ray observatory that was launched on June 11, 2008. Before launch, the observatory was known as the Gamma-Ray Large Area Space Telescope (GLAST). The primary instrument is the Large Area Telescope (LAT), which makes observations of sources of gamma radiation above 20 MeV with unprecedented sensitivity. The GBM will augment the science from Fermi by observing gamma-ray bursts from 10 keV to 30 MeV, covering the energy range of previous experiments. Together, the GBM and the LAT provide gamma-ray burst observations covering over six decades of energy.

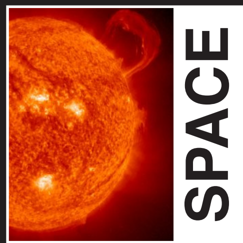
The GBM consists of 12 sodium iodide (NaI) scintillation detectors, covering the 10 keV to 1 MeV energy range, and 2 bismuth germanate (BGO) scintillation detectors, covering the 150 keV to 30 MeV energy range. The detectors are positioned so that any burst will illuminate at least one BGO detector and four NaI detectors. On-board software computes the direction to the burst using the relative count rates on the NaI detectors. For particularly intense bursts, this information is used to reorient the spacecraft to place the burst within the LAT field of view.

Fermi completed a two-month activation period and is now performing routine science observations. Both instruments and the spacecraft have been performing extremely well. GBM has been detecting on average about five gamma-ray bursts per week.

Figure 13

Fermi was launched on June 11, 2008.

GBM is a collaboration among scientists at MSFC, the University of Alabama in Huntsville, the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, and the Los Alamos National Laboratory.



X-Ray Astronomy

Martin C. Weisskopf, Max Bonamente (UAH), Ronald Elsner, Jessica Gaskin, Kajal Ghosh (USRA), Mikhail Gubarev, Marshall Joy, Stephen O' Dell, Brian Ramsey, Doug Swartz (USRA), Allyn Tennant, and Slava Zavlin (USRA)

The X-ray Astronomy Team at MSFC is engaged in several activities in this exciting scientific field. Research activities include scientific research with the Chandra X-ray Observatory; a high energy balloon program including the development of X-ray imaging detectors and X-ray focusing and imaging optics; measurements of the Sunyaev-Zel'dovitch (S-Z) effect in clusters of galaxies with a number of ground-based telescopes; development of instruments for planetary exploration; and participation in hardware development and planning for a number of future astrophysics missions such as the International X-Ray Observatory, the Energetic X-ray Imaging Survey Telescope, Xenia, and the Wide Field X-Ray Telescope Mission. The team collaborates with a large number of outside institutions and involves graduate students both from the local university and elsewhere.

Astrophysical research The X-ray Astronomy Team conducts basic astrophysical research on topics including cosmology, clusters of galaxies, active galactic nuclei, supernova remnants and neutron stars, X-ray binaries, and solar-system bodies. Much of the team's astrophysical research uses data from NASA's Chandra X-ray Observatory, for which the team fulfills the Project Science function.

Members of the team participate in a collaborative study of clusters of galaxies and their use as cosmological probes. The major project within this study combines radio measurements of the S-Z effect (a microwave decrement in the cosmic background due to scattering in cluster gas) with X-ray observations of galaxy clusters to constrain experimentally the cosmological models, measure the cosmic distance scale, and compare observational and theoretical galaxy cluster scaling relations. Figure 14 shows the S-Z radio array. Figure 15 displays a result of current work determining the distance–redshift relation.

Figure 14 **The S-Z array, an 8-element interferometer**

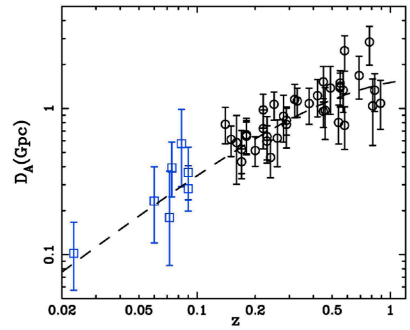


Figure 15

The cosmic distance scale. Distance measurements for galaxy clusters from Chandra X-ray data and S-Z-effect measurements.

Figure 16

The Crab Nebula and pulsar in composite X-ray (blue) and optical (red) image

Figure 17

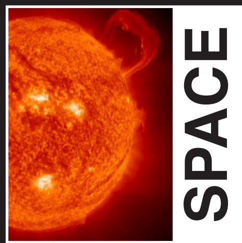
A 0.5-m-diameter X-ray mirror fabricated at MSFC

In addition to the S-Z research, the team also studies ultra-luminous X-ray sources in galaxies, supernova remnants, and pulsing X-ray sources—especially the Crab Nebula and its pulsar (Figure 16). In addition, the team observes X radiation from the planets and from the moons of Jupiter.

Replicated Optics In collaboration with the Sensors, Imaging and Optics Branch, the X-ray Astronomy Team is developing nickel replicated X-ray optics both to meet the demands of future missions and for a variety of current applications. The nickel replication process, wherein nickel mirror shells are electroformed on high-precision mandrels replicating their precise figure and surface, was chosen for this development as it provides full-shell optics with inherently good angular resolution (Figure 17).

Our replicated optics development currently achieves under 25 arcseconds resolution at energies up to 75 keV and is striving towards light-weight, higher precision optics with a goal of 5 arcseconds. A balloon program forms the centerpiece of MSFC replicated optics development and research.

HERO, for High Energy Replicated Optics, is a balloon-borne X-ray telescope system. It features 96 in-house-fabricated nickel-alloy hard-X-ray mirrors focused on to 8 custom-built focal plane detectors. The complete payload (Figure 18), designed and built at MSFC, features a gyroscopically controlled pointing system with purpose-built star cameras designed for both day and night use. The system permits autonomous control during flight, after the desired celestial coordinates have been uploaded. Typical flight durations are 24 hours,



X-Ray Astronomy (continued)

during which time 6-8 targets can be observed. The next scheduled flight of HERO is in the Spring of 2010, from Alice Springs, Australia, to image the center of our galaxy.

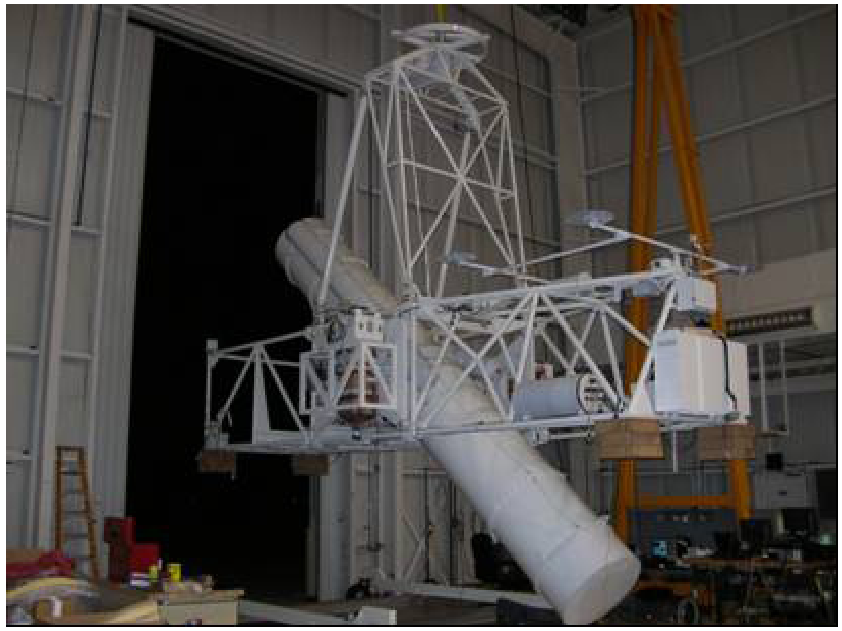


Figure 18 **The HERO payload being tested in the Columbia Scientific Balloon Facility hangar in New Mexico. The payload and gondola systems were designed and built at MSFC.**

FOXSI, for FOcusing X-ray Solar Imager, is a rocket payload being developed by the University of California, Berkeley that will utilize 49 X-ray mirror shells supplied by MSFC. FOXSI is designed to image high-energy X-rays from solar microflares, and will be launched in late 2010 from White Sands Missile Range.

Replicated X-ray optics also have potential for use in medical imaging. Through a collaboration with Lawrence Livermore National Laboratory and with funding provided by the National Institute for Health, an X-ray optical system is being developed to provide radionuclide imaging of small animals. This non-invasive process is designed to assess biological and biomolecular interactions through the labeling of appropriate compounds with radioactive tracers. Such studies have the potential to benefit biomedical research on a wide range of human conditions.

An additional application of replicated optics is for low-energy neutrons which have similar wavelengths to X-rays. The X-ray team has already demonstrated neutron focusing with small X-ray optics and, in a collaboration with MIT, will be receiving Department of Energy funding for additional development.

Instrumentation The team also has two instrument projects related to planetary exploration. Under the NASA Planetary Instrument Definition and Development Program, the X-ray team has been collaborating with Brookhaven National Laboratory for the past three years on the development of a modular X-Ray Spectrometer (XRS) consisting of an array of Silicon Drift Detectors (SDD) for measuring the abundances of light surface elements (C to Fe) fluoresced by ambient radiation (Figure 19).

This instrument's very low power consumption (compared to traditional charge coupled devices) permits large collecting areas and higher sensitivity. For lunar use, the SDD-XRS will be able to finely map crater basins and lava flows and identify materials that originate from the deep lunar interior by observing crater central peaks and impact ejecta. The SDD-XRS could also help pinpoint the most appropriate landing sites and give valuable information regarding in-situ resource utilization on a useful scale (~2km x ~2km area).

The intrinsic radiation resistance of the SDD makes it applicable, in modified form, even to the harsh environment of the Jovian system where it can be used to map the light surface elements of Europa, one of Jupiter's moons. Located in an intense radiation field, this moon is bombarded with a large flux of electrons and ions which give rise to X-ray fluorescence characteristic of the surface elements. The instrument would distinguish these lines against a large background continuum to give a unique measure of Europa's surface composition while in orbit around it. In addition, it can also measure emission from the other Galilean moons, and from Jupiter itself, all with unprecedented sensitivity.

Over the past three years the X-ray team has also developed and tested proof-of-concept components for a miniaturized Environmental Scanning Electron Microscope (mESEM) capable of 100 nanometer or better spatial resolution, in-situ topographical imaging and compositional X-ray fluorescence mapping of uncoated natural and synthetic samples (Figure 20).

Funding has also been provided by the Planetary Instrument Definition and Development Program to design, build and test proof-of-concept components of the mESEM to be used on a future lunar rover. This instrument will aid in planetary resource mapping, space weathering studies of exposed materials, and studies of lunar and eventually Martian material, all pertinent to achieving and maintaining a lasting human presence on a remote planetary surface.

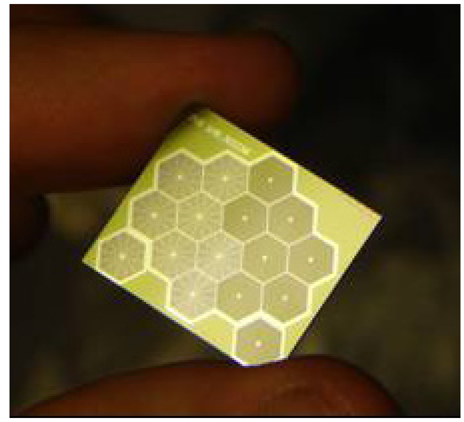


Figure 19

A test array of hexagonal-shaped silicon drift detectors

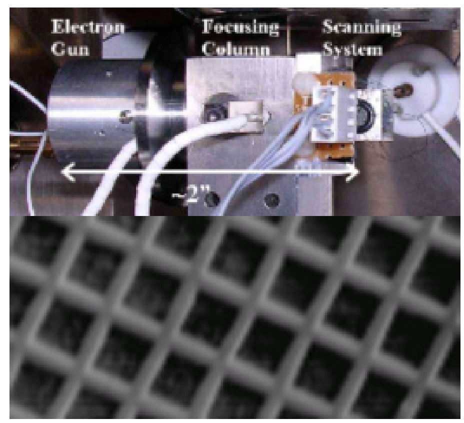
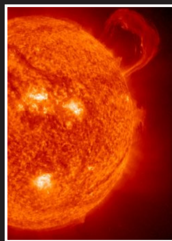


Figure 20

Miniature electron microscope components and the first image



SPACE

Space Radiation Environment

Jim Adams, John Watts and Nasser Barghouty

The ionizing radiation environment in space represents a hazard for human exploration and a challenge to the spacecraft reliability. This environment includes cosmic ray and solar energetic particle radiation. Near the Earth and other planets with magnetic fields, this environment also includes radiation trapped in the magnetic fields. On the surface of the moon and other airless bodies, in addition to these radiations coming directly from space, there is albedo radiation, principally neutron albedo, coming from the surface.

The Cosmic Ray Astrophysics Team at MSFC is revising their model of the space radiation environment available in CREME96 (https://creme96.nrl.navy.mil/). This is part of a larger effort with Vanderbilt University.

In addition, the team is collaborating with the University of Alabama in Huntsville to improve predictions of hazardous solar energetic particle events. By monitoring the magnetic field patterns on the solar surface, we can predict the probability of hazardous events for the next 1 or 2 days. We have also found that after the event occurs, it is possible to predict the time history and intensity of the solar particle flux at Earth (or the moon) over the coming 1 or 2 days. These capabilities are being prepared as operational prediction tools for the Space Radiation Analysis Group at Johnson Space Center, the group responsible for real-time management of radiation doses for space crews.

In earlier work, the Cosmic Ray Astrophysics Team has carefully estimated the relative contribution of neutron albedo to the radiation hazard on the moon during periods when the external radiation environment is dominated by galactic cosmic rays and solar energetic particles. We found that the effective dose from neutron albedo is principally due to neutrons in the $0.1 \leq E \leq 300$ MeV range.

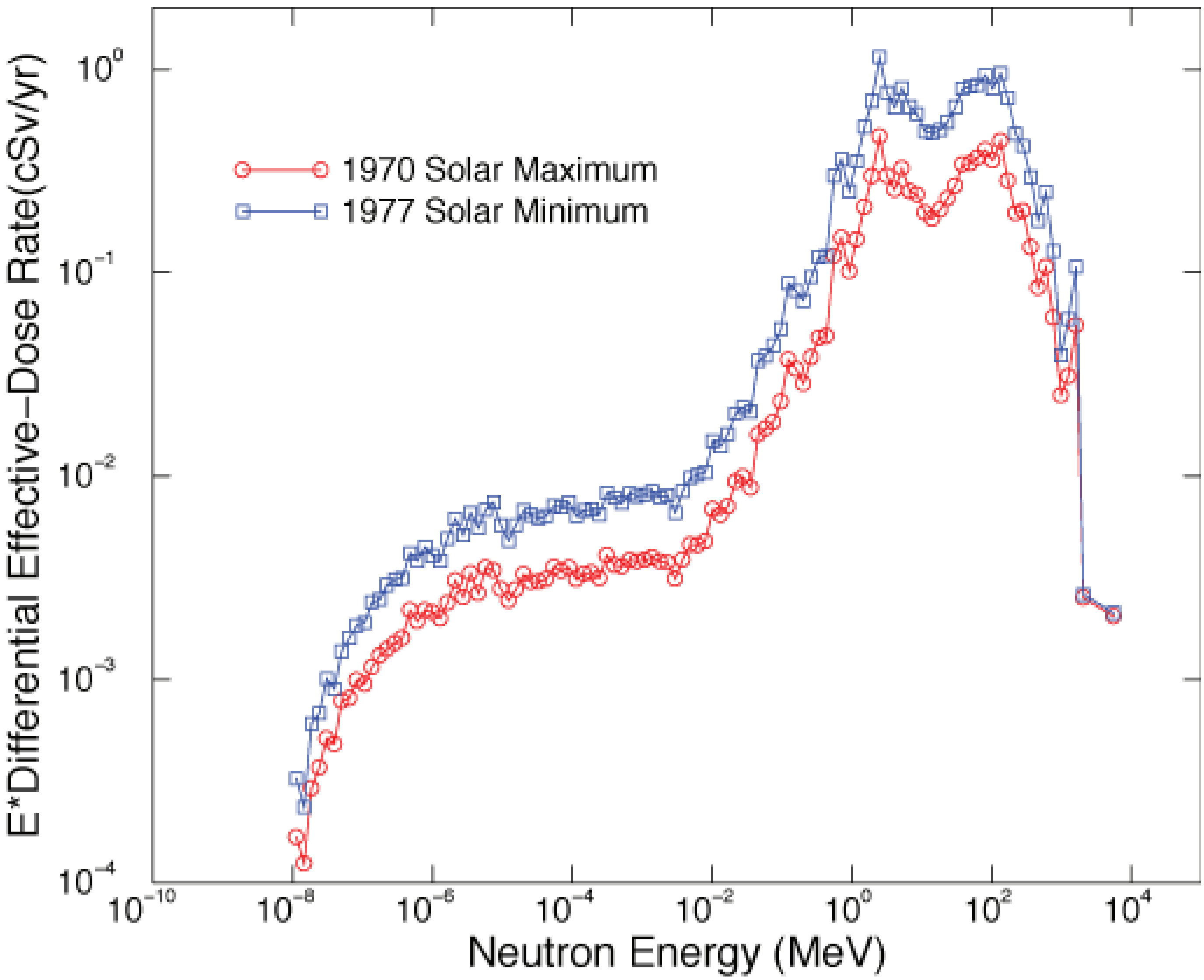
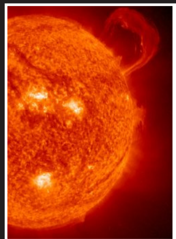


Figure 21 **Effective dose rate from neutron albedo for the minimum of the solar activity cycle in 1977 (when the cosmic ray flux is highest) and for the maximum solar activity cycle in 1970 (when the cosmic ray flux was lowest)**

The fractional contribution to the effective dose from neutron albedo is 18% when the external environment is dominated by galactic cosmic rays at solar maximum, and 16% at solar minimum when the effective dose due to galactic cosmic rays is the highest. These contributions are comparable to the absolute uncertainty in predictions of the galactic cosmic ray flux. During a large solar energetic particle event, the neutron albedo contributed only about 2% of the effective dose. These results are presented in "The Ionizing Radiation Environment on the Moon" by J.H. Adams, M. Bhattacharya, Z.W. Lin, G. Pendleton and J.W. Watts, Advances in Space Science, in press, (2007).

Data from the MSFC Cosmic Ray Astrophysics Team will help characterize the lunar environment in order to plan protective measures for lunar exploration more effectively.



SPACE

The Galactic Cosmic Ray Electron Spectrum

Jim Adams, Mark Christl and John Watts

Measurements made by the Advanced Thin Ionization Calorimeter (ATIC) experiment have led to discovery of an unexpected feature in the cosmic ray electron spectrum.

Figure 22 shows the ATIC measurement of the cosmic ray electron (negatron + positron) spectrum from 20 to 2500 GeV along with the spectrum as predicted by a combination of the GALPROP general electron spectrum (A.W. Strong and I.V. Moskalenko, Adv. *Space Res.* **27**, 717-726, 2001) and the predicted electron spectrum from the annihilation of Kaluza-Klein (KK) dark matter candidate particles as predicted by Cheng, Feng and Matchev Cheng, Phys. Rev. Lett., 89, 211301 (2002). This result has been published in the journal *Nature*.

No model predicts the observed excess between 200 and 1000 MeV. This feature might be due to a previously undiscovered nearby cosmic ray electron source such as a supernova remnant, pulsar, (F.A. Aharonian et al., J. Phys. G, 17, 1769, 1991) or micro-quasar (S. Heinz, and R. Sunyaev, Astronomy and Astrophysics, 390, 751-766, 2002). Another explanation is that these additional electrons come from electron-positron pairs created by the annihilation of KK particles. This explanation gives the best fit to the data.

The ATIC collaboration is lead by Louisiana State University, and its members include the Cosmic Ray Astrophysics Team at MSFC.

The MSFC Cosmic Ray Astrophysics Team is also leading an Advanced Concept Study of the Orbiting Astrophysical Spectrometer in Space (OASIS). The OASIS instrument would provide the most detailed direct measurement data for both cosmic ray electrons and nuclei to determine if there are any nearby sources of cosmic rays and if the source(s) are predominantly in young associations of O-B stars. OASIS would measure and identify the elemental composition and spectra up to the “knee” in the spectra observed by ground based detectors.

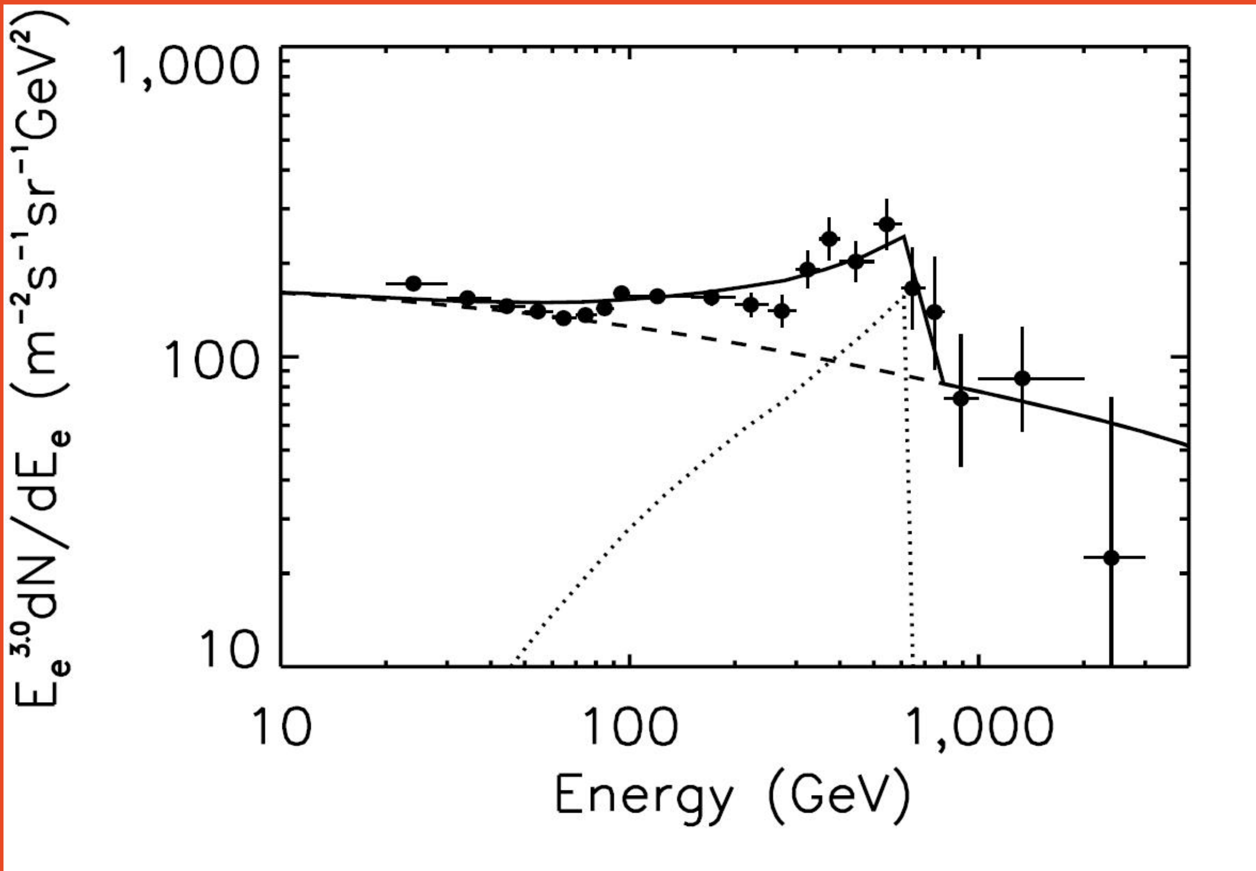
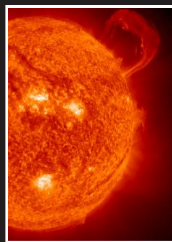


Figure 22 **Assuming a KK dark matter annihilation signature, all the data can be reproduced. The GALPROP general electron spectrum resulting from sources across the galaxy is shown as the dashed line. The dotted curve represents the propagated electrons from the annihilation of KK particles. The dotted curve assumes an isothermal dark matter halo of 4 kpc scale height, a local DM density of 0.43 GeV/cm^3, a KK mass of 620 GeV, and an annihilation cross section rate of 1 x 10^{-23} cm^3/s.**



SPACE

Measurements of Physical and Optical Properties of Individual Cosmic and Lunar Dust Grains

Mian M. Abbas, Dragana Tankosic, Paul D. Craven, Andre C. LeClair, Richard B. Hoover, Edward A. West, and James F. Spann

Dust grains constitute a major component of matter in the universe. About half of elements in the interstellar medium heavier than helium are in the form of dust. Micron/sub-micron size cosmic dust grains play an important role in physical and dynamical process in the galaxy, the interstellar medium, and the interplanetary and planetary environments. Knowledge of the physical, optical, and charging properties of the cosmic dust provides valuable information about many issues dealing with the role of dust in astrophysical environments.

Dust in the Interstellar Medium: Dust particles are formed in astrophysical environments by processes such as stellar outflows and supernovae. Ejected into the interstellar medium, they lead to the formation of diffuse and dense molecular clouds of gas and dust.

Cosmic Dust Cycle: The gas and dust in the interstellar clouds undergo a variety of complex physical and chemical evolutionary processes leading to the formation of stars, and planetary systems, forming a cosmic dust cycle.

Dust in the Interplanetary Medium: The Interplanetary Dust Cloud constitutes the dust in the interplanetary medium extending from the inner solar system to the asteroidal belt. Zodiacal light is the visible light scattered by dust particles in the Interplanetary Dust Cloud. Particles in the Interplanetary Dust Cloud spiral towards the Sun (Poynting-Robertson effect) with lifetimes ~10^4-10^5 years and are evaporated or driven out of the solar system. The sunlight absorbed and reradiated in the infrared by the dust dominates the sky in the 3-70 μm spectral region.

Dust in the Lunar Environment: Apollo astronauts found lunar dust to be unexpectedly high in adhesive characteristics, sticking to the suits, instruments, and the lunar rover. Lunar Surveyor Spacecraft and the Lunar Ejecta & Meteorite Experiment on Apollo 17 indicated the presence of transient dust clouds. A horizon glow over the lunar terminator and high altitude streamers were observed by the astronauts on the Apollo 17 spacecraft. This lunar dust phenomenon is attributed to the electrostatic charging of the dust grains by UV photoelectric emissions on the day side leading to positively charged grains. On the night side, the electron or ion collisions, generally lead to negatively charged grains, with low energy electrons (< 100 eV) dominating the charging process. Secondary electron emissions induced by solar wind electrons with sufficiently high energy may produce positively charged grains. Measurements of the optical and physical properties of *individual lunar* dust grains are required for understanding and mitigating hazardous effects of the lunar dust phenomena.

Experimental Facility at MSFC for Measurements on Individual Micron Size Dust Grains:
MSFC has developed an experimental facility based on an electrodynamic balance for investigation of the properties of individual micron/submicron size dust grains in simulated space environments. We have conducted several unique experiments in this facility to investigate properties and processes of astrophysical interest, employing dust grains comprising the analogs of cosmic dust as well as the dust grains selected from the sample returns of the Apollo 17 and Luna 24 missions. These experiments include the following: (1) first laboratory measurements of radiation pressure on individual micron size dust grains; (2) first laboratory measurements of rotation of micron-size grains simulating the rotation and alignment of dust grains in the interstellar medium that lead to the polarization of star light (investigations of these processes could help evaluate galactic magnetic fields and understand the impact of rotational dust bursting phenomena in the interstellar and interplanetary environments); and (3) laboratory measurements of the photoelectric efficiencies for charging of the analogs of individual cosmic and lunar dust grains by UV radiation, indicating results that are substantially different from the only available measurements made on bulk materials reported in the literature

We are now focusing on the charging of lunar dust by electron impact, simulating the charging of lunar dust by the solar wind plasma. The future work will include: investigation of the condensation of volatile gases on interstellar type dust grains cryogenically cooled to temperatures of ~ 10-30K with formation and growth of icy mantles; and measurements of the infrared optical properties in the middle- and far-infrared spectral regions (10 – 2500 cm^{-1}.) of the icy mantles along with the growth rates.

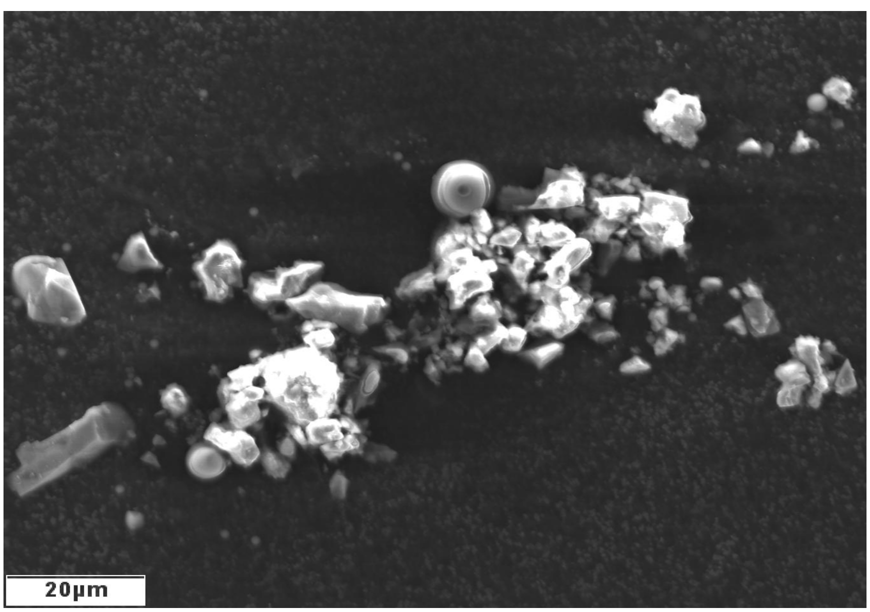
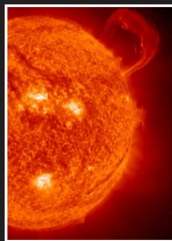


Figure 23

SEM images of Apollo 17 dust



SPACE

Lunar and Planetary Science

Barbara Cohen

Current U.S. Space Policy has turned the nation's attention toward extending our human presence in the solar system, beginning with a return to the moon. The return to the moon will enable the pursuit of scientific activities that address our fundamental questions about the history of Earth, the solar system and the universe, and will provide a test bed for technologies, systems, flight operations and exploration techniques to reduce the risk and increase the productivity of future missions to Mars and beyond.

Lunar science is fundamental to lunar exploration. The mineralogy of the surface, its history and evolution, its physical properties and behavior, and its geophysical parameters, hold the key to answering a range of scientific questions necessary to advancing our understanding of the moon and our goals for lunar exploration. Our team's research combines laboratory analysis of small planetary samples with remotely collected data from spacecraft to interpret planetary surface processes -- including how and when volcanoes, water, and impact craters were active shapers of the moon, Mars, and asteroids.

One of the important outstanding goals of lunar science is understanding the bombardment history of the moon and calibrating the impact flux curve for extrapolation to the Earth and other terrestrial planets. Our team's research has helped revolutionize our view of the early impact history of the moon, revealing a dynamic epoch of bombardment 500 million years after planetary formation. Yet, the cataclysm is not just some lunar oddity. Lunar bombardment history is intimately and uniquely intertwined with both the Earth and Mars, where the role of early intense impacts and possible periodicity in large impact events in the recent past on the atmosphere, environment, and early life underpin our understanding of habitability. We continue to work on understanding the impact history of the inner solar system through petrology, geochemistry, and geochronology of terrestrial crater samples, different kinds of meteorites, and returned lunar samples and lunar meteorites. We also are active on the science team of the Mars Exploration Rover mission to understand the impact process and its products on the Martian surface.

As we conduct scientific research, our team uses our knowledge to guide future exploration activities. The Lunar Precursor Robotics Program (LPRP) program office located at Marshall Space Flight Center is leading the way back to the moon with two precursor missions that will enable sustained human exploration of our solar system: the Lunar Reconnaissance Orbiter (LRO) and the Lunar CRater Observation and Sensing Satellite (LCROSS). The LRO objectives include finding safe landing sites, locating potential resources, characterizing the radiation environment, and demonstrating new technology. The LCROSS mission will excavate and eject lunar surface material from a permanently shadowed crater to investigating the existence of water on the moon.

In addition to the LPRP program, NASA has established the Lunar Quest Program at MSFC to plan future lunar science flight projects designed to accomplish key scientific objectives and, when possible, provide results useful to the Exploration Systems Mission Directorate (ESMD) and the Space Operations Mission Directorate (SOMD) as those organizations grapple with the challenges of returning humans to the moon. First among these missions is the Lunar Atmosphere and Dust Environment Explorer (LADEE), an orbital mission that will characterize the moon's tenuous atmosphere before it becomes permanently disturbed by exploration activities. Next, an MSFC/APL partnership is designing a set of small landed payloads as part of the International Lunar Network (ILN), which will emplace a geophysical network on the moon to understand the structure and composition of the lunar interior. MSFC's lunar flight projects provide a robotic lunar science program for the next decade, help us build a robust lunar science community, and increase international participation in NASA's exploration plans.

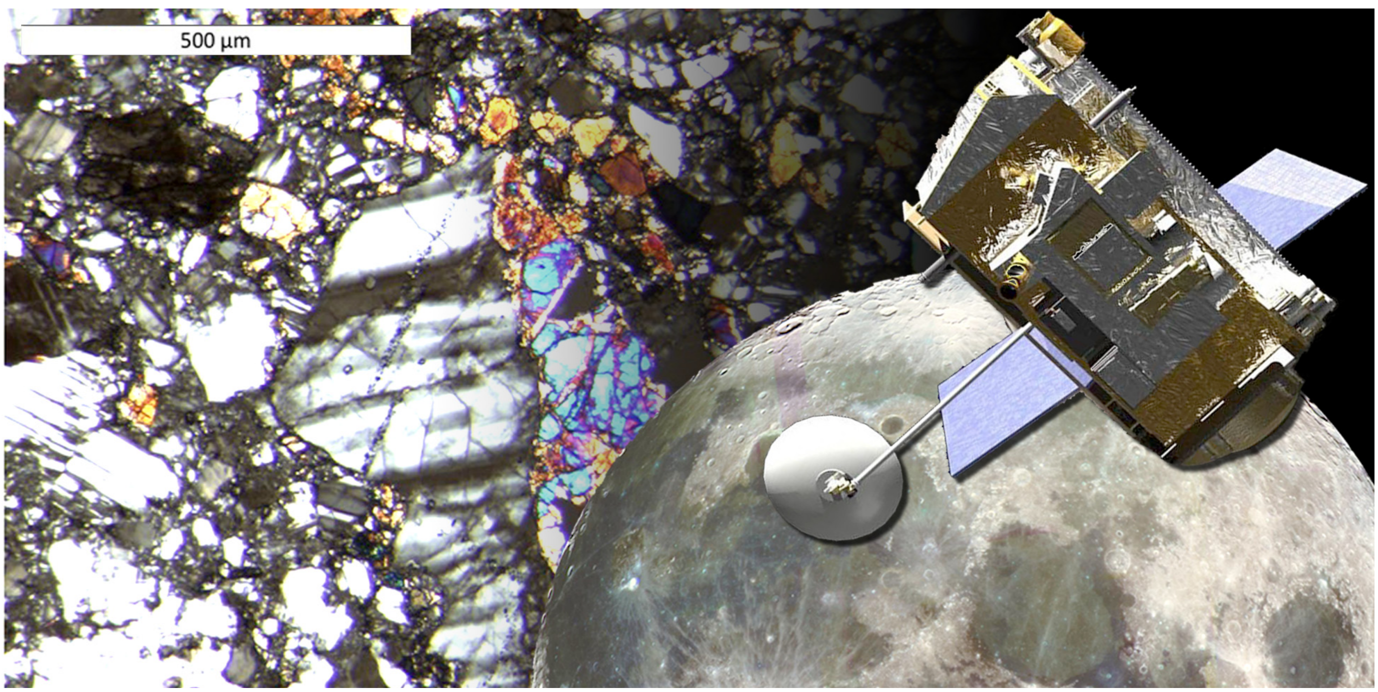


Figure 24 **Top: Thin section photograph (cross-polarized light) of lunar sample 62236, a rock from the lunar crust returned by Apollo 16. The black-and-white minerals are feldspar, an aluminosilicate mineral that makes up the lunar crust; brightly-colored (high birefringence) minerals are olivine, a magnesium silicate mineral dominant in the lunar mantle. Evidence of this rock's complex shock history can be seen in the center feldspar grain, with a faulted string of inclusions. Bottom: The Lunar Reconnaissance Orbiter (LRO) mission, managed under MSFC's Lunar Precursor Robotics Program, will acquire data, including high-resolution imagery, topography, thermal and radiation environments, and lighting conditions, to help humans return to the moon.**

OPTICS

Ares V Science Utilization

H. Philip Stahl

For decades, launch vehicle mass and volume constraints have limited space telescopes and driven programmatic cost and risk. NASA's planned Ares V launch vehicle reduces these constraints and opens the door for launching massive telescopes.

The Ares V is projected to have the ability to deliver ~180,000 kg to LEO and ~60,000 kg to L2 inside a 10-meter diameter fairing. Furthermore, Ares V is expected to provide the ability to accelerate very large payloads to unprecedented velocities (C3). Such a launch capability enables entirely new space science missions ranging from an 8-meter class UV/optical space telescope to replace Hubble; to an 8-meter class X-ray telescope follow-on to Chandra; to entirely new classes of planetary missions including sample return missions.

Additionally, the mass and volume capacities of the Ares V enable a new mission design paradigm – *simplicity*. Mission planners can reduce total mission lifecycle cost and risk by taking advantage of extra mass and volume capacity to design simpler albeit more massive and larger missions by using mature high-TRL technology, fewer deployments, less complexity and more robust design margins.

A large-aperture multi-purpose UV/optical space observatory at L2 would be a significant improvement over existing space and ground telescopes. Such an observatory would help scientists (1) firmly establish the timeline for the reionization of neutral hydrogen in the universe; (2) map the large-scale distribution of baryonic ('ordinary') matter; (3) identify the processes governing galaxy and star formation; (4) establish the processes that drive planet formation; (5) determine the physical characteristics of a large sample of exosolar gas giant and terrestrial planets; and (6) look for bio-signatures from planets orbiting within the habitable zones of nearby stars.

An 8-meter class UV/visible telescope would be 10 times more sensitive than Hubble and would be diffraction limited at a wavelength 4 to 8 times shorter than the James Webb Space Telescope. A wide-field imager (~10 arcmin field-of-view) sitting behind

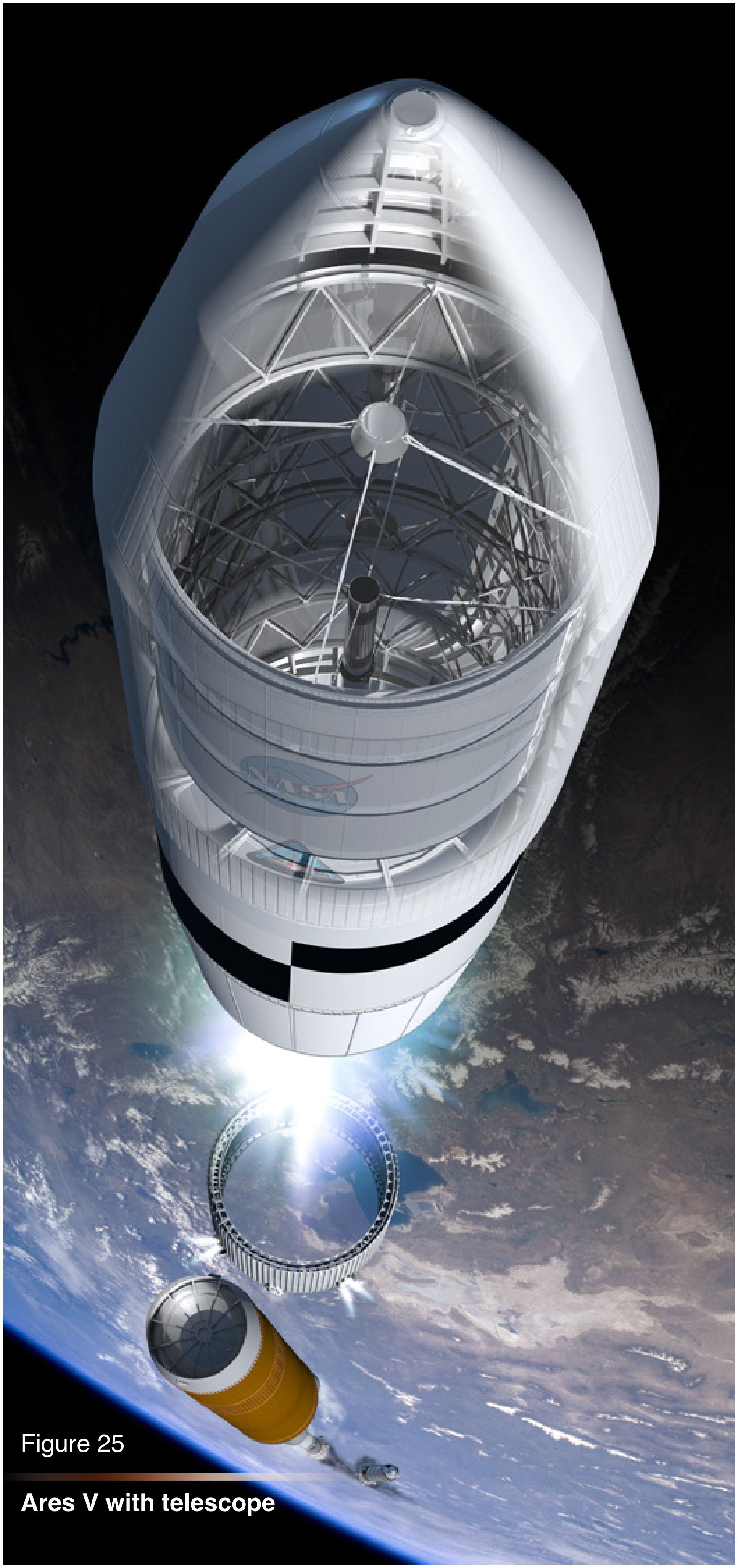


Figure 25

Ares V with telescope

an 8-meter class optical space telescope would provide breakthrough science by enabling surveys covering many square degrees of sky to sensitivities better than 30th magnitude, yielding a probe of the universe 1,000 times the volume of the various Hubble deep fields combined.

The higher sensitivity and the UV window (only accessible from space) will enable the imaging of faint hot stellar populations in nearby galaxies and enable spectroscopy of the faint absorption lines from the 'missing baryons' and from hot Jupiters. A monolithic mirror will provide a circularly symmetric point spread function with well-behaved wings, and the space environment will provide a narrower and much more stable point spread function and a wider field-of-view than those provided by a 30-m telescope on the ground with adaptive optics. Such sensitivity, coupled with the high angular resolution (~0.02 arcsec; about four times better than expected for the James Webb Space Telescope) and a stable point spread function, will provide a completely new view of the universe.

NASA MSFC's Optics Office and Advanced Concepts Office personnel have performed an engineering feasibility study of launching a 6-meter class monolithic primary mirror UV/optical telescope via an Ares V, and are currently preparing an 8-meter point design.

X-Ray & Cryogenic Facility (XRCF)

Jeff Kegley

Our X-ray & Cryogenic Facility (XRCF) is a unique, dual-purpose X-ray optical and direct-incidence cryogenic optical test facility. As the largest X-ray optic and telescope calibration test site in the world, the XRCF was designed and built to perform ground test and calibration of the Chandra X-ray Observatory X-ray mirrors and detectors. Subsequent modifications to the facility have added a unique capability to test large aperture, long radius of curvature, direct-incidence optics at sub-liquid nitrogen temperatures (to 20 Kelvin).

Preparations for James Webb Space Telescope Primary Mirror Segment Assemblies

MSFC Optics Test Office personnel have been preparing for the upcoming James Webb Space Telescope (JWST) Primary Mirror Segment Assembly (PMSA) tests. The JWST primary mirror is composed of 18 individual hexagonal mirrors. Each mirror segment is approximately 1.2 meters across the flats. XRCF will be utilized to perform the flight PMSA optical verification from Feb 2009 to October 2011. The XRCF has been fully engaged this year in support of JWST.

Figure 26

Preparing to lift JWST Engineering Development Unit in XRCF clean room

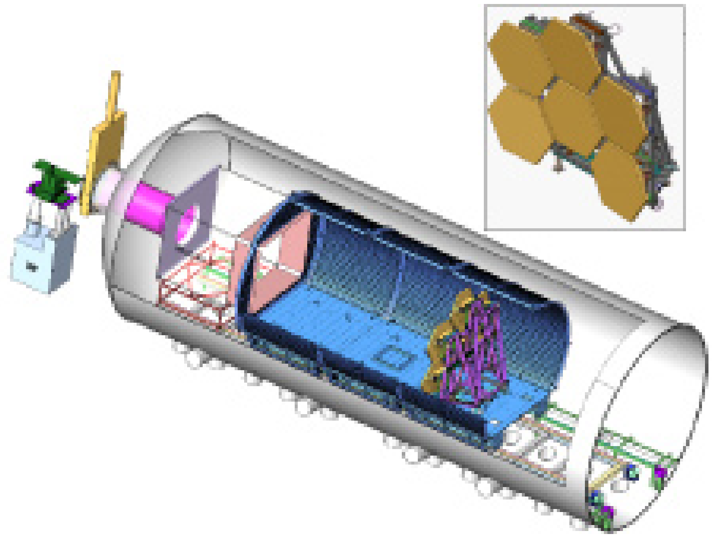


Figure 27

Six mirror PMSA test configuration at XRCF

Chamber Reconfiguration Test office personnel reconfigured the XRCF chamber to the JWST PMSA test configuration. We then conducted a series of chamber operations to verify various requirements in support of JWST. These operations included the following:

- Empty Chamber Elevated Temperature Bake-Out
- Helium Shroud Cleanliness Level Verification Test
- Helium Refrigeration System Performance Verification Test
- Test Stand Cleanliness Level Verification Test
- Ground Support Equipment Cryogenic Certification Tests

Instrumentation Area Reconfiguration We reconfigured the instrumentation area to the JWST PMSA test configuration, rebuilding the wooden floor and walls of this area out of aluminum and installing a large three-axis motion stage. We installed a six-axis motion stage, the instrumentation pallet, atop the three-axis stage. To accommodate viewing the test article, we installed a tilt-window and fiducial cameras outside the vacuum chamber. We then enclosed the entire area in a portable clean tent to maintain the environment around the optical instrumentation pallet.

Radius of Curvature Optic & Translation System A Radius of Curvature Optic (ROCO) will be used by JWST to verify the radius of curvature metrology between flight mirror tests. XRCF personnel designed, fabricated, and verified a ROCO translation system. The ROCO translation system and ROCO were installed in the chamber to perform verification activities this year.

Engineering Development Unit The Engineering Development Unit (EDU), a potential spare flight mirror, was delivered to the XRCF in late September for handling dry-runs and ambient temperature metrology verifications. See Figure 26. The EDU returned to Ball Aerospace for further processing.

Other Support for James Webb Space Telescope

The XRCF supported the Integrated Science Instrument Module team by rapidly performing a test in the small cryo-optical chamber. Five Single Crystal Silicon (SCS) samples were delivered to XRCF in the summer. Each sample consisted of two 50mm diameter flat SCS wafers bonded together with epoxy. An interferometer was used to measure the thermally-induced distortion of each SCS flat caused by differential coefficients of thermal expansion at 290K, 100K, and 35K. The data from this sixteen day effort will be used to inform designs of the Integrated Science Instrument Module and the Primary Mirror Backplane Support Structure.

Abbreviations and Acronyms

APL	Applied Physics Laboratory
BGO	Bismuth Germanate
CATHALAC	Water Center for the Humid Tropics of Latin America and the Caribbean
CREME96	An update of the Cosmic Ray on Micro-Electronics code, a widely-used suite of programs for creating numerical models of the ionizing-radiation environment in near-Earth orbits and for evaluating radiation effects in spacecraft.
EDU	Engineering Development Unit
EPA	Environmental Protection Agency
ESD	Earth Science Division
ESMD	Exploration Systems Mission Directorate
FOXSI	FOcusing X-Ray Solar Imager
GALPROP	a numerical galactic cosmic ray propagation code (not an acronym)
HELIX	Health and Environment Linked for Information Exchange
HIRAD	Hurricane Imaging Radiometer
ILN	International Lunar Network
IWP	Ice Water Path
KF	Kain-Fritsch [parameterization]
KK	Kaluza-Kelien
LADEE	Lunar Atmosphere and Dust Environment Explorer
LCROSS	Lunar Crater Observation and Sensing Satellite
LPRP	Lunar Precursor Robotics Program
LRO	Lunar Reconnaissance Orbiter
MAPIR	Marshall Airborne Polarimetric Imaging Radiometer
mESEM	miniaturized Environmental Scanning Electron Microscope
NaI	Sodium Iodide
NSSTC	National Space Science and Technology Center
OASIS	Orbiting Astrophysical Spectrometer in Space
O-B [stars]	Hot, massive stars which form in loosely organized groups called OB associations.
PMSA	Primary Mirror Segment Assembly
ROCO	Radius of Curvature Optic
SCS	Single Crystal Silicon
SDD	Silicon Drift Detectors
SEM	Scanning Electron Microscope
SFMR	Stepped Frequency Microwave Radiometer
SHEELS	Simulator for Hydrology and Energy Exchange at the Land Surface
SMAP-VEX	Soil Moisture Active Passive Verification Experiment
SOMD	Space Operations Mission Directorate
STScI	Space Telescope Science Institute
USRA	Universities Space Research Association
UV	Ultraviolet
XRS	X-Ray Spectrometer

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